NASA TECHNICAL TRANSLATION

NASA TT F-401

NASA TT F-401

UNITARY VERTICAL CONDUCTION CURRENTS AS A MEASURE OF THUNDERSTORM ACTIVITY FOR THE ENTIRE SURFACE OF THE EARTH

by N. A. Paramonov

From *Meteorologicheskiye Issledovaniya,*
No. 9, 1965

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1965

NASA TT F-401

UNITARY VERTICAL CONDUCTION CURRENTS AS A MEASURE OF THUNDERSTORM ACTIVITY FOR THE ENTIRE SURFACE OF THE EARTH

By N. A. Paramonov

Translation of "Unitarnyy vertikal'nyy tok provodimosti kak mera grozovoy deyatel'nosti dlya vsey poverkhnosti zemli." Meteorologicheskiye Issledovaniya, No. 9, pp. 167-173, Izdatel'stvo "Nauka," Moscow, 1965.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – Price $1.00

UNITARY VERTICAL CONDUCTION CURRENTS AS A MEASURE OF THUNDERSTORM ACTIVITY FOR THE ENTIRE SURFACE OF THE EARTH

N. A. Paramonov

ABSTRACT

Relationship between the unitary vertical conduction current and the thunderstorm activity for the entire earth's surface was investigated. This relationship proved to be rather close, which is a good reason to consider the unitary vertical conduction current as a criterion of the thunderstorm activity for the entire earth's surface.

A vertical conduction current in the atmosphere may be regarded /167* as the sum of two components. One component changes with respect to world time, and its changes are called a unitary variation. The other component changes with the local time, and its changes are called a local variation. It can be readily seen that the unitary variation of the vertical conduction current is caused by a factor which is general for the entire earth. The majority of researchers are inclined to assume that it is caused by thunderstorm activity. This opinion was first held by C. T. R. Wilson (Ref. 1). In order to substantiate this opinion, F. J. W. Whipple (Ref. 2) compared the diurnal variation in thunderstorm activity for the entire surface of the earth with the diurnal variation in the potential gradient observed over the oceans (Ref. 3), where primarily unitary variations occur (both gradients of the potential and the vertical conduction current). The curves which were formulated closely coincided. In order to pursue further research on this subject, it was necessary to compare the annual unitary variation in the vertical conduction stream and the potential gradient with the annual variation of thunderstorm activity. Data were published in 1950 (Ref. 4) on the unitary annual variation in the potential gradient. A comparison of the unitary annual variation in the potential gradient with the annual variation in thunderstorm activity [curves obtained by C. E. P. Brooks (Ref. 5) K. P. Ramakrishnan (Ref. 6), and H.-Ch. Krumm (Ref. 7)] showed that they occur in the opposite phase.

*Note: Numbers in the margin indicate pagination in the original foreign text.

This result caused additional interest in this subject. Attention was called to the fact that, in the statistics of C. E. P. Brooks (Ref. 5) and others (Ref. 6, 7), only the number of thunderstorms on the earth were taken into account. The subject under consideration does not, in the last analysis, deal with the number of thunderstorms, but rather with the inflow of a charge to the earth caused by the thunderstorms, upon which the surface density of the earth's charge, the magnitude of the potential gradient, and the vertical conduction current depend.

The magnitude of the charge transmitted to the earth via a lightning channel naturally depends on the physical-geographical conditions. It is impossible to equate thunderstorms at high and low latitudes in terms of intensity and charge transfer - for example, the thunderstorms of Murmansk and Brazil.

According to the statistics given by Brooks and other authors, the total number of thunderstorms on the earth is greater in the summer (north) than in the winter; however, in summer they predominate in the moderate latitudes, and in winter they predominate at the lower latitudes. At the lower latitudes, the thunderstorms are more intense and the magnitude of the charge transmitted to the earth via lightning is considerably greater than at the moderate latitudes. Therefore, it can be assumed that the maximum of the charge transmitted to the earth will not occur in summer - when a maximum in the number of thunderstorms is observed - but in winter, when the thunderstorms are particularly intense. The charge which is transmitted from the thunder clouds to the surface of the earth, charges it and creates a field. Under the influence of this field, a /168 conduction current is formed in the atmosphere. Thus, both the potential gradient and the vertical conduction current must be related to thunderstorm activity.

The vertical conduction current is $i = v' (\lambda_+ + \lambda_-)$, where v' is the potential gradient of the electric field in the atmosphere; $\lambda_+ + \lambda_-$ - total conductivity of the air. For a constant value of $\lambda_+ + \lambda_-$, the connection between thunderstorm activity and both the potential gradient and the vertical conduction current must be the same. However, the conductivity of the air is always changing everywhere, and in addition it changes in local time. These changes in the air conductivity produce local changes in the potential gradient, which suppress the relationship between thunderstorm activity and the potential gradient. The changes in the vertical conduction current are subjected to local influence to a lesser extent; the unitary changes to which thunderstorm activity is related are more sharply expressed in it than in the potential gradient. Therefore, unitary changes can be more readily, and more accurately, distinguished in observations on the vertical conduction current than in observations on the potential gradient. In this connection, it is advantageous to relate thunderstorm activity to an unitary vertical conduction current.

The purpose of the present article is to study the extent to which the unitary vertical conduction current and thunderstorm activity are related, taking into account the charge transfer via lightning to the entire surface of the earth. In the event that a close relationship is found, the purpose of this article is then to formulate the following problem: the unitary vertical conduction current as the measure of thunderstorm activity for the entire surface of the earth.

Let us examine this relationship with respect to the diurnal, seasonal, and multi-year variation.

The charge transfer $Q_{j,\ell}$ to the surface of the earth $S_{j,\ell}$ can be determined by the following formula:

$$Q_{j,l} = S_{j,l} n_{j,l}(\varphi)\, t(\varphi)\, m(\varphi)\, k(\varphi)\, q(\varphi), \qquad (1)$$

Where $n_{j,\ell}$ is the number of days per year having a thunderstorm, or per season; φ - geographic latitude; t - hourly duration of thunderstorm; m - number of lightning strokes on $1 km^2$ per 1 hour; k - increase in negative lightning strokes over the positive strokes in fractions of a unit; q - lightning charge transmitted to the earth.

The quantities n, t, m, k, q may depend on the geographic latitude φ. The values of n can be readily found on maps showing the days having thunderstorms. The quantities t, m, k, q, according to data from our observations, are approximated by the following formulas:

$$\left.\begin{aligned} t &= t_0 e^{-a_1\varphi^2} = 2{,}08 e^{-1{,}32\varphi^2}, \\ m &= m_0 e^{-a_2\varphi^2} = 0{,}07 e^{-2{,}47\varphi^2}, \\ k &= k_0 e^{-a_3\varphi^2} = 0{,}89 e^{-1{,}32\varphi^2}, \\ q &= q_0 e^{-a_4\varphi^2} = 16{,}1 e^{-2{,}63\varphi^2}, \end{aligned}\right\} \qquad (2)$$

where φ is used to designate $\varphi/90$.

The quantities t_0, k_0, q_0, a_1, a_3, a_4 were calculated by means of formula (2) from the individual values of t, k, q taken from observational data shown in Tables 1, 2, 3. It must be pointed out that not all of the data are presented in these tables, but only the data which correspond to natural conditions and which are the most reliable. Table 3 presents the mean values of the total current in one lightning channel; other characteristics are presented in the literature, in addition to these. Naturally, these data are insufficient for an accurate determination of all the parameters of formula (2) and the quantity Q. However, they make it possible to determine them in the first approximation and to provide a quantitative characterization of the relationship under consideration. /169

TABLE 1

MEAN DURATION OF THUNDERSTORM ACCORDING TO DATA IN 1957-1961

Station	Mean geographic latitude for a group of stations, N°	Mean duration of thunderstorm, hours
Murmansk, Voyeykovo	64.47	1.15
V. Dubrava, Irkutsk, Kiev	53.13	1.34
Odessa, Dusheti, Tashkent	42.28	1.61

TABLE 2

COEFFICIENTS OF K AND RELATIONSHIP BETWEEN NUMBER OF LIGHTNING STROKES ON THE EARTH HAVING POSITIVE AND NEGATIVE POLARITY.

Observational point	Geographic latitude	Lightning polarity	k	Source
Sweden	60°N	2.9:1	0.49	(Ref. 8,9)
Sweden	60	2.7:1	0.46	(Ref. 10)
USSR	56	3.2:1	0.52	(Ref. 8,9)
England	52	3.5:1	0.55	(Ref. 8,9)
Germany	50	5.8:1	0.70	(Ref. 10)
Switzerland	47	6.0:1	0.71	(Ref. 8,9)
USSR, Caucusus	47	4.8:1	0.66	(Ref. 8,9)
United States		4.0:1	0.66	(Ref. 8,9)
United States	40	9.0:1	0.80	(Ref. 10)
OAR	30	All negative	1.00	(Ref. 8)
South Africa	25°S	17.0:1	0.89	(Ref. 10)

TABLE 3

MEAN VALUE OF CHARGE TRANSMITTED TO THE EARTH DURING ONE LIGHTNING DISCHARGE

Observational point	Geographic latitude, N°	Charge in coulombs	Source
New Mexico	32-35	12	(Ref. 10)
Upsala	60	5	(Ref. 11)

The quantities m_o and a_2 were calculated by means of the formula $m = m_o e^{-\alpha^2\varphi^2}$ and by means of the values for m obtained from a map (Ref. 12) showing the distribution of a number of strong lightning strokes on the earth. After substituting formula (2) in (1), we obtain the following equation:

$$Q_{j,l} = 2{,}09 \cdot S_{j,l} n_{j,l} e^{-7{,}58 \cdot \varphi^2}. \qquad (3)$$

The following formula was employed to summarize $Q_{j,\ell}$ over the entire surface of the earth: /170

$$Q = 2{,}09 \cdot e^{-7{,}58 \cdot \varphi} \sum_j \sum_l S_{j,l} n_{j,l} \qquad (4)$$

The summation was performed in terms of longitudinal intervals with the index j, and in terms of the latitude intervals with the index l.

The lightning current on the earth was determined by the formula:

$$i_{K} = \frac{Q}{t}, \qquad (5)$$

where t is the time required for the inflow of the charge Q during a year or season, expressed in seconds.

The diurnal variation in the charge Q, transmitted to the entire surface of the earth, was determined with the aid of formula (4) and maps showing the distribution of the number of days having thunderstorms. $Q_{j,\ell}$ were calculated for each element of the earth's surface, defined by 15 degrees longitude and 10 degrees latitude. The latitudinal index j assumed values from 1 to 18; the longitudinal index l - from 1 to 24.

$Q = \sum_{i=1}^{18} Q_{j_o}$ was calculated for each interval of the geographic longitude equalling 15° for the continents and the oceans separately. Then each value of Q_j for the continents was divided by 24 hourly values, in accordance with the mean diurnal variation in atmosphere activity over the continents, and each value of Q_j for the oceans was divided by 24 hourly values, in accordance with the mean diurnal variation in thunderstorm activity over the ocean. The separate statistics for Q_j for continents and oceans is caused by a significant difference in the diurnal variation of thunderstorm activity (compare the date given on page 6).

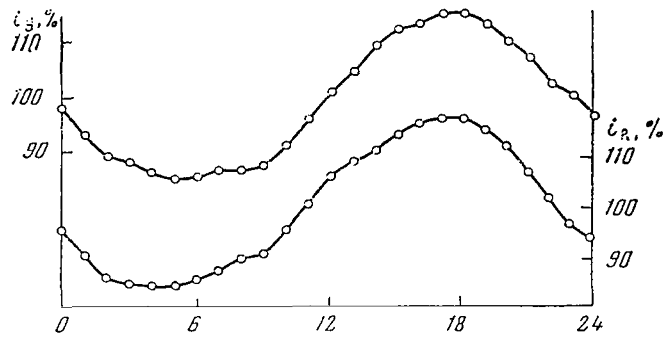
The diurnal variation in thunderstorm activity for the continents is obtained from data from 18 typical stations located at different latitudes. It is determined for the oceans from 10 ocean stations. For the majority of the continental stations, the diurnal variations in thunderstorm activity did not differ considerably from each other. Therefore, when dividing Q_j by 24 hourly values, we employed the mean. The mean diurnal variation in recurrence of thunderstorms (in fractions of a unit) is as follows:

Hours	Conti-nents	Oceans	Hours	Conti-nents	Oceans
0-1	0.032	0.063	12-13	0.056	0.027
1-2	0.026	0.049	13-14	0.076	0.032
2-3	0.022	0.055	14-15	0.089	0.037
3-4	0.016	0.050	15-16	0.092	0.044
4-5	0.014	0.045	16-17	0.087	0.050
5-6	0.013	0.041	17-18	0.084	0.055
6-7	0.012	0.035	18-19	0.071	0.060
7-8	0.009	0.029	19-20	0.061	0.064
8-9	0.008	0.024	20-21	0.050	0.067
9-10	0.009	0.020	21-22	0.045	0.070
10-11	0.018	0.022	22-23	0.042	0.068
11-12	0.033	0.024	23-24	0.037	0.066
	Total			1	1

For individual ocean stations, the diurnal variations in thunderstorm activity differed to a somewhat greater extent, but the variation obtained from eight typical ocean stations did not differ significantly from that obtained from ten stations. Thus, one mean diurnal variation in thunderstorm activity can be employed for the ocean.

Thus, 24 lines were obtained with 24 hourly values of $Q_{j,k}$ (the index k takes on values from 1 to 24, just as does j) for the continents and for the oceans. They were arranged according to Greenwich time and summed up in columns for each hour for the continents and oceans separately, and then together. In this way, data were obtained on the diurnal variation Q (in Greenwich time) throughout the entire surface of the earth. By dividing each hourly value of Q by time, equalling one year and expressed in seconds, during which these Q reached the earth, we obtained the magnitude of the lightning current ($i_{\lessgtr}$) for each hour of the day. It is then expressed in % of $i_{\lessgtr}$ of the mean. A clearer and more detailed description of a similar processing method can be found in the work (Ref. 5). /171

The diurnal variation in the density of the vertical conduction current (i_{λ}) is obtained from our observations of the potential gradient and the conductivity of air above the oceans (Ref. 3, 13), where only unitary variations in the potential gradient and vertical conduction current were primarily discovered.



Greenwich Time

Figure 1

Diurnal Variation in Unitary Vertical Conduction Current and Lightning Current Throughout the Entire Surface of the Earth

It can be readily determined that the diurnal variation in the unitary vertical conduction current, falling on the entire surface of the earth (I_y%), can be written as follows:

$$I_y = \sum_j \sum_l S_{j,l} i_{j,l}, \tag{6}$$

where $i_{j,\ell}$ represents the density of the unitary vertical conduction current which changes in world time and has the same wave form i.e., the same amplitude and period, which corresponds fairly closely to averaged observational data. On the basis of the law of summation of harmonics which are identical in terms of amplitude and period (Ref. 14), after summing up expression (6) we obtain a current having the same wave form, relative amplitude, and the same period - i.e.,

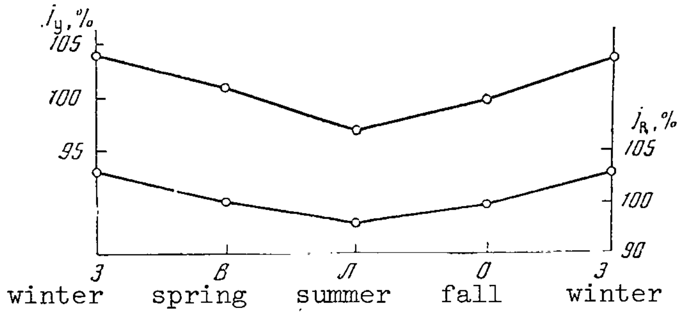
$$I_y = Ai_y.$$

where $A = \sum_j \sum_\ell S_{j,\ell}$ - is a constant quantity. This means that the relative (in %) change in the density of the unitary conduction current will coincide with the relative change in the conduction current falling on the entire surface of the earth.

Figure 1 presents the results obtained. It can be seen from the figure that the curve for the diurnal variation i_K closely coincides with the curve i_y. The correlation coefficient between them is 0.96. The seasonal values of i_K were determined with the aid of expressions (4), (5), and seasonal maps; the number of days having thunderstorms - according to each season of the year; and the values of i_y - according to observational data over the oceans (Ref. 3, 13). /172

The seasonal variation in i_K and i_y is shown in Figure 2, from which it can be seen that these closely coincide. The correlation coefficient between them is 0.90.

The multi-year variation in i_K is obtained from observational data on the number of days having thunderstorms during the year from 818 stations in the Soviet Union and from generalized observational data on the number of days having thunderstorms in the year obtained by C. E. P. Brooks (Ref. 14). These data were reduced to i_K with the aid of formulas (4) and (5).



Seasons of the Year

Figure 2

Annual Variation in Unitary Vertical and Lightning Conduction Currents and Lightning Current Throughout the Entire Surface of the Earth

The mean multi-year variation in i_y was obtained from data derived from simultaneous observations on the potential gradient and air conductivity by 11 stations (Tashkent, Slutsk, Voyeykovo, Dusheti, Tbilisi, Potsdam, K'yu, Aas, Ebro, Waterloo, Uankayo). The following information should be taken into consideration: (1) The lack of adequate multi-year observations on i over the oceans, where unitary variations primarily occur; (2) the results of the work (Ref. 15), where it was shown that the majority of the continent stations primarily obtain the unitary variations in i; (3) the average local random deviations of i, related to meteorological and other phenomena, decreased with an increase in the number of stations employed, according to the law of random deviations $(\overline{\Delta i_\ell} = \Delta i_\ell / \sqrt{n})$;

(4) a detailed analysis of the data from individual stations, which makes it possible to reject data entailing systematic errors.

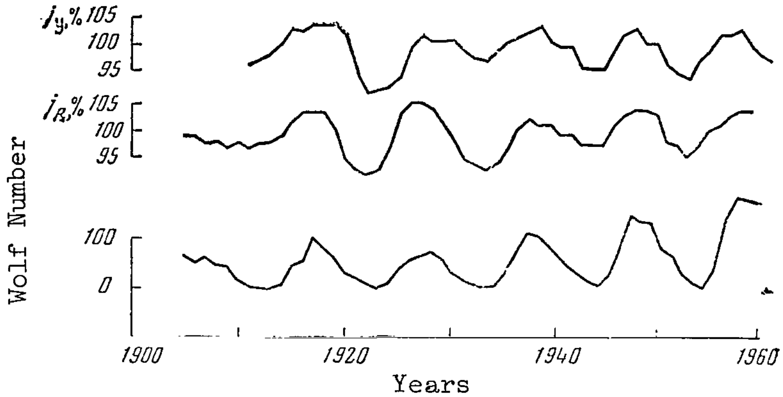


Figure 3

Multi-year Variation in Unitary Vertical Conduction Current, Lightning Current Throughout the Entire Earth, and Number (Wolf) of Sunspots /173

Let us determine the relationship between the mean local change in i and the unitary change, i.e., $(\overline{\Delta i_\ell / \Delta i_y})$. Based on the work (Ref. 16), the mean magnitude of this relationship for an individual station can be determined as 30%. For 11 stations, it will equal

$$\overline{\left(\frac{\Delta i_l}{\Delta i_y}\right)} = \frac{30}{100} \cdot \frac{1}{\sqrt{11}} = \frac{30}{332} = 0{,}09 \text{ (i. e. } 9\%).$$

All of this provides a basis for assuming that the multi-year variation in the mean magnitude of i from 11 stations is primarily connected with the multi-year change in the unitary vertical conduction current.

Figure 3 presents the multi-year variation in i_K and i_y. These curves closely coincide. They also closely coincide with the multi-year variation in the number of sunspots (Wolf number) shown in the same figure. The correlation coefficient between the curves for i_K and i_y is 0.80. Thus, a fairly close relationship is obtained between i_K and i_y in terms of diurnal, annual, and multi-year variation. This can be readily explained, and provides a basis for regarding the unitary vertical conduction current as a measure of thunderstorm activity for the entire surface of the earth. Our study makes it possible to draw the following conclusions.

1. There is a close connection between the unitary vertical conduction current and the lightning current on the entire surface of the earth.

2. The unitary vertical conduction current can be regarded as a measure of thunderstorm activity for the entire surface of the earth.

REFERENCES

1. Wilson, C. T. R. On the Measurement of the Earth-Air Current and on the Origin of Atmospheric Electricity. Proc. Cambridge Philos. Soc., 13, 1906.

2. Whipple, F. J. W. On the Association of the Diurnal Variations of Electrical Potential Gradient in Fine Weather With the Distribution of Thunderstorms Over the Globe. J. Quart. Roy. Meteorol. Soc., No. 229, 55, 1929.

3. Mauchly, S. I. Studies in Atmospheric Electricity Based on Observations Made on the Carnegie 1915-1921. Research Depart. Terr. Magn. Carnegie Inst., 5, 1926.

4. Paramonov, N. A. Annual Variation in the Gradient of the Atmospheric-Electric Potential (O godovom khode gradiyenta atmosferno-elektricheskogo potentsiala). Doklady AN SSSR, No. 1, 71, 1950.

5. Brooks, C. E. P. The Distribution of Thunderstorms Over the Globe. Geophys. Mem., N 3, 1921.

6. Ramakrishnan, K. P. a. Rao, D. S. V. Distribution of Thunderstorms Over the World. Indian J. Meteorol. Geophys.,1, 1955.

7. Krumm, H.-Ch. The Probability of Storms as a Function of World Time (Der weltzeitliche Tagesgang der Gewitterhäufigkeit). Zs. Geophys., No. 2, 28, 1962.

8. Stekol'nikov, I. S. Physics of Lightning (Fizika Molnii). Izd-vo AN SSSR, 1943.

9. Tverskoy, P. N. Atmospheric Electricity (Atmosfernoye elektrichestvo). Gidrometeoizdat, Leningrad, 1949.

10. Norinder, Kh. Studies on Thunderstorm Discharges (Issledovaniya grozovykh razryadov). Gosenergoizdat, 1956.

11. Brook, M., Kitagawa, N., a. Workmann, E. J. Quantitative Study of Strokes and Continuing Currents in Lightning Discharges to Ground. J. Geophys. Res., No. 2, 67, 1962.

12. Brooks, C. E. P. Climate in Everyday Life. London, 1950.

13. Lobodin, T. V. Results of Studies on the Electric Field Over the Ocean (Nekotoryye rezul'taty issledovaniy elektricheskogo polya nad okeanom). Trudy Glavnoy Geofizicheskoy Observatorii (GGO) No. 97, 1960.

14. Brooks, C. E. P. The Variation of the Annual Frequency of Thunderstorms in Relation to Sunspots. J. Quart. Roy. Meteorol. Soc., 60, 1934.

15. Bronshteyn, I. N. and Semendyayev, K. A. Handbook on Mathematics (Spravochnik po matematike). Fizmatgiz, Moscow, 1962.

16. Paramonov, N. A. The Problem of Separating Unitary Changes in Elements of Atmospheric Electricity (K voprosu vydeleniya unitarnykh izmeneniy elementov atmosfernogo elektrichestva). Trudy GGO, No. 110, 1960.

Scientific Translation Service
4849 Tocaloma Lane
La Canada, California

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546